PADS FOR CMP AND POLISHING SUBSTRATES

by

Thomas E. West, Jr.

CROSS REFERENCE TO RELATED APPLICATIONS

The present application claims benefit of provisional United States patent application Docket Number TWI-002, filed on 29 October 2001, entitled "PADS FOR CMP AND POLISHING SUBSTRATES." This application is related to provisional United States patent application Docket Number TWI-004, filed on 29 October 2001, entitled "POLISHING PADS AND MANUFACTURING METHODS." The contents of all of these applications are incorporated herein by this reference in their entirety.

TECHNICAL FIELD

This invention relates to pads for applications such as chemical mechanical planarization (CMP) and polishing of substrates such as semiconductor substrates, wafers, metallurgical samples, memory disk surfaces, optical components, lenses, and wafer masks. More particularly, the present invention relates to CMP pads and pads for polishing and methods of manufacturing pads having improved properties for fabrication of electronic devices.

BACKGROUND

Processes employing CMP or polishing techniques have been widely used to planarize the surface of wafers during the various stages of device fabrication in order to improve yield, performance, and reliability of the fabrication process. In fact, CMP has become essentially indispensable for the fabrication of advanced integrated circuits.

Integrated circuits are chemically and physically integrated into a substrate by patterning regions in the substrate and layers on the substrate. To achieve high yields, it is

usually necessary to recreate a substantially flat substrate after processing steps that leave topographic features on the surface of the wafer, features such as surface irregularities, bumps, troughs, and trenches.

Various types of pads have been developed in efforts to meet the needs of CMP processes and polishing processes. For a more detailed discussion of polishing pads see PCT application W096/15887, the specification of which is incorporated herein by reference. Other representative examples of polishing pads are described in U.S. patents 4,728,552, 4,841,680, 4,927,432, 4,954,141, 5,020,283, 5,197,999, 5,212,910, 5,297,364, 5,394,655 and 5,489,233, the specifications of which are also each incorporated herein in their entirety by reference.

Although polishing pads are in extensive use, a need remains for improved polishing pads which provide effective planarization across electronic device substrates and have improved polishing efficiency, increased removal rates, improved uniformity across the substrate, and longer pad life for lower cost of ownership. In addition, there is a need for new pads that can tolerate the higher temperatures that are needed for advanced CMP processes. Furthermore, there is a need for new pads that possess some of the best properties of different types of pads so that the overall performance of the pad is better than that of the standard technology pads.

SUMMARY

This invention pertains to improve pads for applications such as polishing substrates and CMP of substrates and related methods. The present invention seeks to overcome one or more of the deficiencies of the standard technologies for polishing and/or planarizing substrates.

One aspect of the invention is a pad for applications such as polishing substrates and CMP of substrates. In one embodiment, the pad is substantially hard and has a substantially open pore structure. In preferred embodiments, the pore structure is sufficient for transporting a polishing slurry at a rate that is effective for CMP. Preferably, the pore structure is substantially homogeneous throughout the pad.

Another embodiment of the present invention is a pad for CMP of substrates for electronic device fabrication. The pad includes a non-woven felt and a polymer resin. The

felt is impregnated with the resin so that the pad has a Shore D hardness from about 45 to about 65, a density in the range of about 0.5 grams per cubic centimeter to about 0.7 grams per cubic centimeter, and a compressive modulus greater than about 70%.

Another embodiment of the present invention is a pad for polishing substrates for electronic device fabrication. The pad includes a non-woven felt having a density of about 0.29 to about 0.35 grams per cubic centimeter and a polymer resin. The felt is impregnated with the resin so that the pad has a Shore D hardness from about 47 to about 57, a density in the range of about 0.5 grams per cubic centimeter to about 0.7 grams per cubic centimeter, and a compressive modulus greater than about 70%.

It is to be understood that the invention is not limited in its application to the details of construction and to the arrangements of the components set forth in the following description or illustrated in the figures. The invention is capable of other embodiments and of being practiced and carried out in various ways. In addition, it is to be understood that the phraseology and terminology employed herein are for the purpose of description and should not be regarded as limiting.

As such, those skilled in the art will appreciate that the conception, upon which this disclosure is based, may readily be utilized as a basis for the designing of other structures, methods and systems for carrying out aspects of the present invention. It is important, therefore, that the claims be regarded as including such equivalent constructions insofar as they do not depart from the spirit and scope of the present invention.

Further, the purpose of the foregoing abstract is to enable the Patent Office and the public generally, and especially the scientists, engineers and practitioners in the art who are not familiar with patent or legal terms or phraseology, to determine quickly from a cursory inspection the nature and essence of the technical disclosure of the application. The abstract is not intended to define the invention of the application, which is measured by the claims, nor is the abstract intended to be limiting as to the scope of the invention in any way.

The above and still further features and advantages of the present invention will become apparent upon consideration of the following detailed descriptions of specific embodiments thereof, especially when taken in conjunction with the accompanying figures.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a SEM photograph of a pad according to an embodiment of the present invention.

FIG. 2 is a SEM photograph of a standard technology hard pad.

FIG. 3 is a SEM photograph of a standard technology semi soft pad.

FIG. 4 is a graph showing planarization data for a pad according to an embodiment of the present invention and data for a standard technology pad.

FIG. 5 is a graph showing copper planarization efficiency for a pad according to an embodiment of the present invention.

FIG. 6 is a graph showing polishing results using a pad according to an embodiment of the present invention.

DESCRIPTION

The operation of embodiments of the present invention will be discussed below, primarily, in the context of chemical mechanical planarization. However, it is to be understood that embodiments in accordance with the present invention may be used for general applications of substrate polishing such as grinding, lapping, shaping and polishing of semiconductor substrates, wafers, metallurgical samples, memory disk surfaces, optical components, lenses, and wafer masks.

An embodiment of the present invention is an improved polishing pad for removing material from a substantially solid surface. More particularly, one embodiment of the present invention is a polishing pad for applications such as chemical mechanical planarization such as that used as part of integrated circuit manufacturing processes. Another embodiment of the present invention includes methods for performing chemical mechanical planarization. Still another embodiment of the present invention includes methods for fabricating polishing pads.

Embodiments of the present invention include an improved polishing pad for applications such as chemical mechanical planarization. One embodiment of the present invention is a pad for chemical mechanical planarization of substrates for electronic device

fabrication; the pad is substantially hard and the pad has a substantially homogeneous pore structure sufficient for transporting amounts of CMP slurry effective for CMP processing.

In some embodiments, the pad includes a multiplicity of fibers and a polymer resin. The fibers are arranged so as to form a non-woven mass such as a felt. The polymer resin is applied so as to impregnate the fibers and, consequently, form the pad. For embodiments of the present invention, the resulting pad has properties of the standard technology porous pads and properties of the standard technology hard pads. In other words, embodiments of the present invention are substantially porous and substantially hard so that the pads have one or more of the beneficial CMP characteristics of standard technology porous pads and standard technology hard pads. Specifically, pads according to embodiments of the present invention are harder than the standard technology porous pads and more porous than the standard technology hard pads.

Some embodiments of the present invention have a Shore D hardness from about 45 to about 65 and all subranges subsumed therein. A preferred embodiment has a Shore D hardness from about 47 to about 57 and all subranges subsumed therein. A more preferred embodiment has a Shore D hardness from about 51 to about 54.

Polishing pads according to embodiments of the present invention have porosities that are higher than that for standard technology hard pads and lower than that for standard technology soft pads. The porosity of the pad is related to the density of the pad. Generally, a high porosity corresponds to a low-density and vice versa. Specifically, polishing pads according to the present invention have densities in the range of about 0.5 grams per cubic centimeter to about 0.7 grams per cubic centimeter. In a preferred embodiment, the polishing pad has a density of about 0.58 +/- 0.04 grams per cubic centimeter. Typically, the high-density is preferable for embodiments of the present invention, provided the porosity of the pad is sufficient for transporting slurry. In other words, it is preferable for the pad to be capable of transporting amounts of slurry that may be required for the polishing process or CMP process for which the pad is being used.

The air permeability of a pad for polishing or CMP can be considered an indication of the porosity and the pore structure. Specifically, air permeability is determined by pad properties such as the pore size, porosity, and amount of open pore structure. Some embodiments of the present invention have air permeabilities greater than or equal to about

20 (cubic centimeters)/((square centimeter)(minute)). One of the preferred embodiments of the present invention has air permeabilities in the range of about 24 to about 34 (cubic centimeters)/((square centimeter)(minute)) and all subranges subsumed therein.

Furthermore, some embodiments of the present invention have pore sizes in the range from about 5 micrometers to about 150 micrometers, and all ranges subsumed therein. In some of the preferred embodiments, the pore structure is substantially homogeneous throughout the pad.

A wide range of polymer resins may be used in embodiments of the present invention. Suitable resins include resins such as, for example, polyvinylchloride, polyvinylfluoride, nylons, fluorocarbons, polycarbonate, polyester, polyacrylate, polyether, polyethylene, polyamide, polyurethane, polystyrene, polypropylene, and mixtures thereof. The selection of the resin will depend upon the desired properties of the pad. Preferred embodiments of the present invention include resins that have high hardness values. This means that for resin impregnated felt pads according to preferred embodiments of the present invention, the hardness of the resin is higher than that of resins that are typically used for resin impregnated felt pads according to the standard technology. Typical resins are commercially available from a number of vendors.

The hardness of the resin is related to the 100% modulus value of the resin. This modulus provides a measure of the tensile strength of the resin. One embodiment of the present invention has a 100% modulus value of about 300 kg/cm to about 400 kg/cm. A preferred embodiment of the present invention uses a polyurethane resin having a 100% modulus value of about 350 kg/cm. For purposes of comparison, one of the standard technology porous pads uses a polyurethane resin having a 100% modulus value of about 200 kg/cm.

Various manufacturing techniques can be used to produce polishing pads according to embodiments of the present invention. In one embodiment, the polishing pad includes non-woven fibers comprising polyester and a polymer resin comprising polyurethane. Desirable properties for polishing pads according to embodiments of the present invention can be produced using polyester fibers having a denier of about 2. Those skilled in the art know that embodiments of the present invention can also be made using other deniers, such as for example, deniers in the range of about 1.5 to about 3.0.

Desirable properties for polishing pads according to embodiments of the present invention can be incorporated into the polishing pads by increasing the ratio of fiber to polymer resin in the polishing pad. For some embodiments of the present invention, the ratio of polyester fiber to polyurethane resin is in the range of from about 50:50 to about 65:35, and all ratios and ratio ranges subsumed therein. In other words, the polyester makes up from about 50% to about 65% and subranges subsumed therein. The polyurethane resin makes up from about 50% to about 35% and subranges subsumed therein. Preferred embodiments of the present invention have ratios of polyester to polyurethane of about 55:45.

Notably, the traditional thinking among those skilled in the art is that pad hardness increases with an increase in the resin content. However, some embodiments of the present invention show higher hardness with an increase in the fiber content. This means that some embodiments of the present invention have fiber to resin ratios that are contrary to the standard thinking of those skilled in the art. In other words, the ratio of felt to resin is higher in some embodiments of the present invention than that found in the standard technology pads. Specifically, embodiments of the present invention have higher ratios of polyester fiber to polyurethane than is typically thought desirable for good pad characteristics.

Table 1 summarizes several physical properties of some embodiments of polishing pads according to the present invention.

TABLE 1

Property	Suitable	Preferred
Pad Density gm/cc	0.5-0.7	0.58 +/- 0.04
Fiber to Polymer Resin Ratio	50:50-65:35	55:45
Hardness, Shore D	>47	51-54
Hardness, Shore A		89-98
Felt Density gm/cc		0.32
Pore Size Range um		5-150
Compressibility %		1.8
Resiliency %	70-100	>80

Conventional methods were used for measuring the properties of the pads.

In some instances, the performance of pads according to the present invention has been found to be better than that of standard hard pads. Specifically, using pads according to the present invention have been shown to result in defectivities of about 5 to about 10 for wafers of 200 mm diameter for defects >0.2 micrometers measured on a Tencor® 6420. However, the typical performance for a standard hard pad results in a defectivity of about 20 or greater, under substantially the same process conditions.

Reference is now made to Figure 1 wherein there is shown a photograph taken by SEM of a pad according to an embodiment of the present invention. The pad includes a polyester fiber felt impregnated with a polyurethane resin. Figure 1 shows a surface and side section view of the pad at a magnification of about 100X; the open pore structure can be seen in the photograph. The pad shown in Figure 1 has a Shore D hardness of about 51 to about 54, a density of about 0.59 grams per cubic centimeter, a compressibility of about 1.8 percent, and a rebound of about 85 percent.

For comparison, similar measurements were made for one of the standard technology hard pads. Reference is now made to Figure 2 wherein there is shown a photograph taken by SEM of the standard technology hard pad made of polyurethane. Figure 2 shows the surface of the standard technology hard pad at a magnification of about 100X. The SEM photograph shows that the standard technology hard pad has less pore structure than the embodiment of the present invention shown in Figure 1. The standard technology hard pad shown in Figure 2 has a Shore D hardness of about 52-62, a density of 0.75 grams per cubic centimeter, a compressibility of 2.1 percent, and a rebound of about 73 percent. The pad shown in Figure 2 does not include a felt.

In addition, similar measurements were made for a standard technology semi-soft pad, also referred to as a porous pad. Reference is now made to Figure 3 wherein there is shown a photograph taken by SEM of one of the standard technology semi soft pads at a magnification of about 41X. The semi soft pad has a Shore D hardness of about 30 to about 35, a density of about 0.37 grams per cubic centimeter, a compressibility of about 2.4 percent, and a rebound of about 76 percent.

It appears that pads according to the present invention have some properties that are intermediate to those of standard technology semi soft pads and standard technology hard

pads. As a specific example, the hardness of pads according to embodiments of the present invention is intermediate to that for the standard technology semi soft pad and the standard technology hard pad. As a result, the performance of pads according to the present invention is, in some ways, superior to those of the semi soft standard technology pads and the standard technology hard pads.

Table 2 shows process conditions and results from CMP processes for tungsten using pads according to embodiments of the present invention. The CMP process was performed with a standard commercially available slurry, EKC 3550 W slurry.

TABLE 2

Wafer ID	Down Force (psi)	Table Speed (rpm)	Carrier Speed (rpm)	Flow Rate (ml/min)	Removal Rate (A/min)	Non-Uniformity (%)
A	6	110	95	110	3910	3.5
B	6	110	110	110	3830	4.1
C	5	110	95	110	2690	9.7
D	7	90	95	110	4200	2.9
E	6	110	95	110	4950	5.2
F	6	110	95	80	4100	4.2
G	6	110	95	140	3860	4.9
H	6	90	110	110	2670	11
I	6	110	95	110	3670	7.5
J	7	90	95	110	3540	3.8

Embodiments of the present invention have another advantage over the standard technology pads in terms of erosion during processes such as CMP of tungsten damascene structures. Table 3 shows erosion data for pads according to the present invention and the standard technology pads. In general, pads according to present invention produced less erosion of the oxide during the planarization of tungsten damascene structures.

TABLE 3

Pad Type	0% Over Polish	25% Over Polish	50% Over Polish	100% Over Polish
Embodiment Of Present Invention	400	420	480	650
Standard Technology	210	650	910	1000

The planarization capabilities of pads according to the present invention have been measured. In addition, similar measurements have been performed for the standard technology pads. The experimental results, in general, show that pads according to the present invention have superior planarization capability over that of the standard technology pads. Some of the experimental results are presented in Figure 4. The results in Figure 4 are for an oxide planarization process. The x-axis represents the amount, in Angstroms, of oxide removed; the y-axis represents the remaining step height in Angstroms. These results are for features of 100 micrometer lines and spaces and were obtained using a down force of 4.5 psi. The points resented by diamonds, connected by the solid line are data for a pad according to an embodiment of the present invention. The points represented by squares, connected by the dashed line, are data for a standard technology hard pad. For these measurements, the pad according to the present invention had lower remaining step height for the amount of oxide removed. In other words, the pad according to the present invention is more efficient than the standard technology pad in terms of producing a planar surface. For the results shown in Figure 4, the pad according to the present invention included a polyester felt impregnated with a polyurethane resin; the pad had a Shore D hardness of about 51 to about 54, a density of about 0.59 grams per cubic centimeter, a compressibility of about 1.8 percent, and a rebound of about 85 percent.

Planarization capabilities of pads according to the present invention were also measured for copper planarization. Fig. 5 shows step height, in Angstroms, as a function of removed field copper for planarization using pads according to the present invention. The process conditions were down force 3 psi, table speed 105 rpm, carrier speed 100 rpm,

slurry flow rate 100 ml/minute, and back pressure 0 psi. For the results shown in Figure 5, the pad according to the present invention included a polyester felt impregnated with a polyurethane resin; the pad had a Shore D hardness of about 51 to about 54, a density of about 0.59 grams per cubic centimeter, a compressibility of about 1.8 percent, and a rebound of about 85 percent.

Reference is now made to Figure 6 wherein there is shown performance data for pads according to the present invention. The process data are for a tungsten CMP process using a commercially available slurry, EKC 3550 W slurry. The x-axis represents the wafer number. The y-axis represents either removal rate in angstroms per minute, non-uniformity in percent, or defectivity. The closed diamonds represent tungsten removal rates, WRR. For this set of experiments, the tungsten removal rate varies from about 3800 A/min to about 4800 A/min. The triangles represent removal rates for titanium, TiRR. The open diamonds represent data points for tungsten removal nonuniformities, WNU. The tungsten non-uniformity for this set of experiments have values less than about 10% and in some instances less than or equal to about 5%. The measured defectivities, shown as solid ovals, for this set of experiments are in the range of about 5 to about 10 for wafers having diameters of 200 mm. For the results shown in Figure 6, the pad according to the present invention included a polyester felt impregnated with a polyurethane resin; the pad had a Shore D hardness of about 51 to about 54, a density of about 0.59 grams per cubic centimeter, a compressibility of about 1.8 percent, and a rebound of about 85 percent.

Another advantage of embodiments of the present invention is that the pads are particularly suitable for some of the more advanced CMP processes where higher polishing speeds are required. This improvement, seen in some embodiments of the present invention, is believed to result from the greater stability, such as thermal stability, of the pads according to the present invention.

Pads made according to embodiments of the present invention have been shown to have superior performance compared to that of standard technology pads for several planarization test. Pads according to embodiments of the present invention have, in general, 20 to 25% higher removal rates with the exact same process parameters as solid polyurethane pads, i.e., standard technology hard pads. Pads according to embodiments of the present invention have, in general, a factor of about 2 times to about 10 times lower

defectivity than for the standard technology hard pads. Pads according to embodiments of the present invention have, in general, 40% lower slurry use requirement for maintaining a removal rate that is insensitive to slurry flow. Pads according to embodiments of the present invention, in general, have a long operating life for the pad, typically, about 2 times to about three times that of the standard technology hard pads. Pads according to embodiments of the present invention, in general, require less diamond pad conditioning between each wafer than is required for standard technology hard pads. The required down force is lower for embodiments of the present invention and only one or two sweeps between wafers may be need. Whereas, for standard technology hard pads, the pad conditioners wear out much more quickly than for pads according to embodiments of the present invention. Pads according to embodiments of the present invention, in general, have lower oxide erosion than the standard technology hard pads.

In addition, pads according to the present invention are capable of providing satisfactory polishing characteristics in addition to having substantially longer lifetimes.

While there have been described and illustrated specific embodiments of the invention, it will be clear that variations in the details of the embodiments specifically illustrated and described may be made without departing from the true spirit and scope of the invention as defined in the appended claims and their legal equivalents.